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WIDE ANGLE MICROWAVE SENSOR DESIGN

FINAL REPORT

by

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Table of Contents

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1. ABSTRACT

The main accomplishment of this research effort so far has been the rigorous formulation of the four sensor element spherical array problem. The end results are described here. Field expressions for the sensor elements are given. Next, the radiated field in the outside regions are expressed in terms of spherical waveguide mode fields. Applying electromagnetic field boundary conditions, the radiated field for the main sensor element located at zenith is derived. Next, the radiated field of an arbtrarily located(on the spherical surface) sensor element is derived. Contributions of three auxiliary sensors are then vectorially added to derive the compensatory fields that will augment the performance of the main element off-broadside.

2 . INTRODUCTION

Wide angle microwave and millimeter wave sensors have extensive applications in space exploration and space communications. One practical requirement may need coverage over an entire hemispherical region with circularly polarized fields. In this research, a novel scheme is proposed whereby a primary sensor assisted by three strategically placed auxiliary sensors on a spherical surface provide the required coverage. Rigorous field analysis and design of such an array is presented here.

In one version the array consists of circular apertures on a conducting spherical surface. the main element is placed at the zenith. The other three identical auxiliary circular aperture elements are placed in a ring configuration 120^{0} apart at an angle θ_a off-broadside(polar axis) as shown in Figure 1. Each circular aperture element is excited with circular polarization for the transmit case or is capable of extracting circularly polarized fields in the case of reception.

In another version, the sensor elements are circular microstrips with similar behavior. Such microstrip elements consists of circular conducting patches on a dielectric substrate above the conducting spherical surface. Their performance are similar to that of the circular apertures.

The design goal is to perform a rigorous analysis to find out what should be the radius of the conducting spherical surface and what should be the location(θ_a) of the three element auxiliary ring so that the desired performance objective could be achieved for a given center frequency of operation. The design then could be extended to multi-band operations.

Field representations and the four element array formulation are described next.

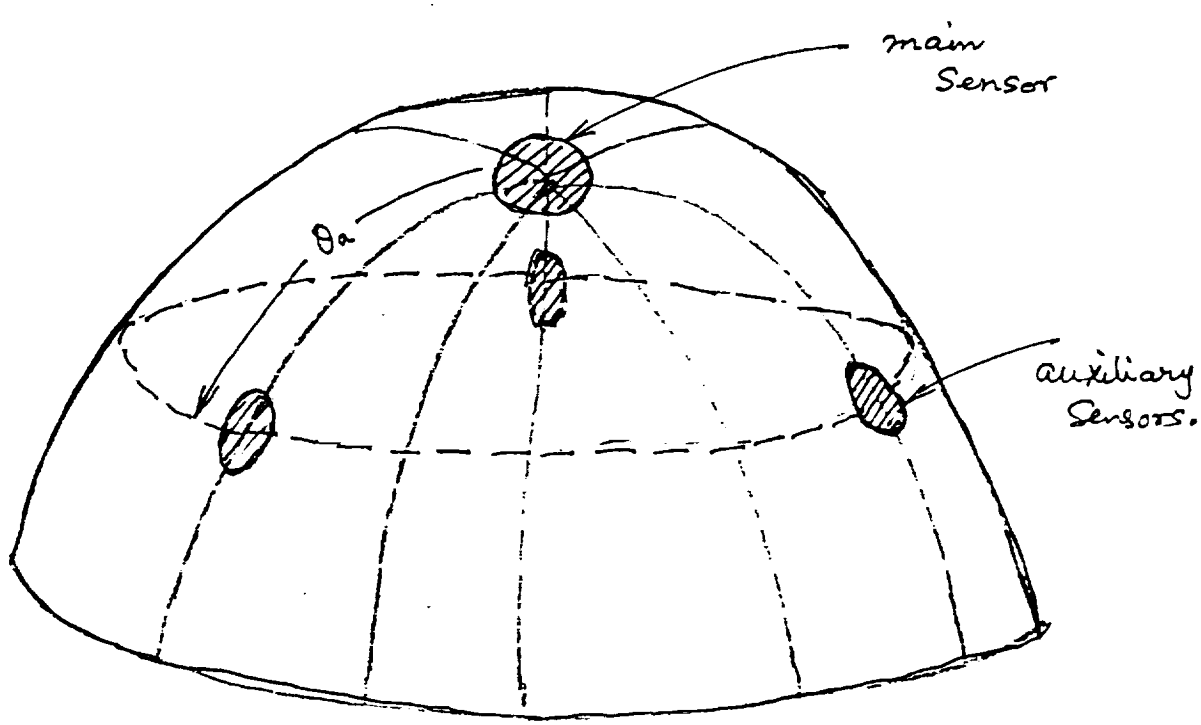

Figure 1: SCHEMATIC OF THE FOUR ELEMENT SENSOR ARRAY

3 . SENSOR ELEMENT DESCRIPTION AND DESIGN

The global coordinate frame(r, θ , ϕ) in the spherical geometry is defined with the polar axis through the zenith. The local coordinates (r, θ' , ϕ') are defined with the polar axis through the center of the respective aperture or microstrip element which is located at (θ_a , ϕ_a) in the global coordinate frame.

The sensor fields are represented in terms of orthogonal circular cylindrical eigen modes. In this report we will deal with the aperture type elements. Circular microstrip element currents have similar current expressions but requres a different boundary value problem solution. Neglecting curvature effects to the extent of the aperture(or the microstrip element), the sensor electric field for the local θ_o-directed polarization is expressed as:

$$\overline{E}^s_t(\theta',\phi') = E^s_o A\left\{-\overline{\theta}'_o\left(\frac{\hat{\theta}}{u\theta'}\right) J_1\left(\frac{u\hat{\theta}}{\theta'}\right)\cos\phi' + \overline{\phi}'_o J'_1\left(\frac{u\hat{\theta}}{\theta'}\right)\sin\phi'\right\} \quad \ldots \quad (1)$$

whereas for the local ϕ_o-directed polarization the electric field is given by:

$$\overline{E}^s_{tc}(\theta',\phi') = E^s_{oc} A\left\{+\overline{\theta}'_o\left(\frac{\hat{\theta}}{u\theta'}\right) J_1\left(\frac{u\hat{\theta}}{\theta'}\right)\sin\phi' + \overline{\phi}'_o J'_1\left(\frac{u\hat{\theta}}{\theta'}\right)\cos\phi'\right\} \quad \ldots \quad (2)$$

where A is a normalization constant.

4) FIELD REPRESENTATIONS IN THE EXTERIOR SPHERICAL REGION

Viewing space as a spherical transmission line, the electromagnetic fields in the exterior region are represented in terms of spherical waveguide modes[1] and are given as:

$$\overline{E}_t(r,\theta,\phi) = \sum_{p=1}^{2}\sum_{n=1}^{\infty}\sum_{m=0}^{n}\frac{V_{pmn}(r)}{r}\overline{e}_{pmn}(\theta,\phi) \qquad \ldots(3)$$

$$\overline{H}_t(r,\theta,\phi) = \sum_{p=1}^{2}\sum_{n=1}^{\infty}\sum_{m=0}^{n}\frac{I_{pmn}(r)}{r}\overline{h}_{pmn}(\theta,\phi) = \sum_{p=1}^{2}\sum_{n=1}^{\infty}\sum_{m=0}^{n}\frac{V_{pmn}(r)}{Z_{pn}(r)}\overline{h}_{pmn}(\theta,\phi) \qquad \ldots(4)$$

where the terms have standard meaning in the context of the present analysis.

We define two spherical coordinate frames. The global coordinate frame(r, θ , φ) is defined with polar axis through the center of the main aperture(zenith) whereas the local coordinate frame(r, θ' , φ') is defined with polar axis through the center of the respective aperture. Spherical coordinate transformation is necessary for determining the array field.

6) RADIATION FIELD OF THE PRINCIPAL SENSOR AT THE ZENITH

The radiated field for the principal aperture sensor element has been derived for the ϕ_o-directed polarization excitation and is given below:

$$\overline{E}_t(r \to \infty, \theta, \phi) = -\frac{e^{-jkr}}{r} V_{aux} \Big[\overline{\theta}_o \sum_{n=1}^{\infty} \frac{(j)^n}{\sqrt{2\pi}} \frac{\sqrt{(2n+1)}}{n(n+1)} \Big\{ \frac{W_{1n}}{H'^{(2)}_n(kR)} \frac{d}{d\theta} P^1_n(\cos\theta) - j \frac{W_{2n}}{H^{(2)}_n(kR)} \cdot \frac{P^1_n(\cos\theta)}{\sin\theta} \Big\} \sin\phi + \overline{\phi}_o \sum_{n=1}^{\infty} \frac{(j)^n}{\sqrt{2\pi}} \frac{\sqrt{(2n+1)}}{n(n+1)} \Big\{ \frac{W_{1n}}{H'^{(2)}_n(kR)} \frac{P^1_n(\cos\theta}{\sin\theta} - j \frac{W_{2n}}{H^{(2)}_n(kR)} \cdot \frac{d}{d\theta} P^1_n(\cos\theta) \Big\} \cos\phi \Big]$$

. . . (5)

A similar expression has also been derived for the θ_o-directed polarzation excitation.

7) RADIATION FIELD OF THE ARRAY OF THREE AUXILLIARY SENSOR ELEMENTS

Following extensive field analysis, the total radiated field for the three element ring array at an angle θ_a off the zenith and placed 120^0 apart in ϕ . The expressions are given below:

$$\overline{E}_t^{aux}(r \to \infty, \theta, \phi) = -\frac{e^{-jkr}}{r} V_{aux} \left[\overline{\theta}_o \sum_{n=1}^{\infty} \frac{(j)^n}{\sqrt{2\pi}} \frac{\sqrt{(2n+1)}}{n(n+1)} \frac{W_{1n}}{H_n^{\prime(2)}(kR)} \frac{d}{d\theta} P_n(\cos\theta_{aux}) \frac{d}{d\theta} P_n(\cos\theta) \right]$$

...(6)

for the identical θ_o-directed polarization excitation of each auxiliary element.

and

$$\overline{E}_t^{aux}(r \to \infty, \theta, \phi) = -\frac{e^{-jkr}}{r} V_{aux} \left[\overline{\phi}_o \sum_{n=1}^{\infty} \frac{(j)^{n+1}}{\sqrt{2\pi}} \frac{\sqrt{(2n+1)}}{n(n+1)} \frac{W_{2n}}{H_n^{(2)}(kR)} \frac{d}{d\theta} P_n(\cos\theta_{aux}) \frac{d}{d\theta} P_n(\cos\theta) \right]$$

...(7)

for the identical ϕ_o-directed polarization excitation of each auxiliary element.

9 . REFERENCES

1. L.B. Felsen and N. Marcuvitz, *Radiation and scattering of Waves*, Prentice Hall, New Jersey,1973, chapter 2, pp.218-232 and chapter3, pp. 314-323.